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# THE AMERICAN METEOROLOGICAL JOURNAL.

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TABLE OF CONTENTS.


**Original Articles:** PAGE

Flood-Stage River Predictions. Prof. THOMAS RUSSELL . . . . . . . 47

The First Scientific Balloon Voyage. R. DE C. WARD . . . . . . . 58

Snow-Storms at Chicago. A. B. CRANE . . . . . . . 63

The Eye of the Storm. SIDNEY M. BALLOU . . . . . . . 67

Shall we Erect Lightning Rods? ALEXANDER MCADIE, M. A. . . . . . 84

**Current Notes:**

New England Meteorological Society . . . . . . . 93

Royal Meteorological Society . . . . . . . 94

Exposure of Rain-Gauges . . . . . . . 95

English Weather Forecasts . . . . . . . 95

Avalanches and Wind-Flurries . . . . . . . 95

**Bibliographical Notes:**

Investigations of the New England Meteorological Society . . . . . . 97

**Correspondence:**

A Remarkable Rainbow . . . . . . . 98

**Editorial Note** . . . . . . . 98



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THE AMERICAN

METEOROLOGICAL JOURNAL.

VOL. IX. BOSTON, MASS., JUNE, 1892. No. 2.

# FLOOD-STAGE RIVER PREDICTIONS.

PROF. THOMAS RUSSELL, U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU.

A RIVER stage is the vertical height of the water surface above the plane of low water. It is observed with a gauge, which consists of a plank graduated to feet and tenths fastened to a bridge pier or laid along the incline of a river-bank.

There are about one hundred and fifty gauge stations, maintained at various points on principal rivers throughout the country on streams subject to overflow. The river stages at these places are observed daily. These observations are the basis of crest-stage predictions made from time to time. The crest stage is the highest water occurring during a rise. When a high stage occurs at a place, it occurs later on at a point lower down the stream. The accumulated records of gauge readings for years past afford the means of deriving rules by which the predictions are made.

Rainfall alone is of very little use in making river predictions. In the case of a few places it is, however, used in forming an estimate of a coming high stage of water.

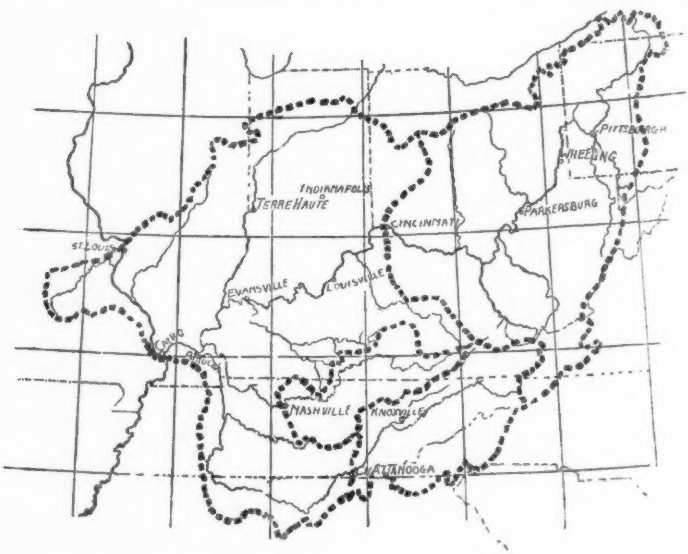
A river surface is in a perpetual state of oscillation — continually rising or falling. The rivers reflect roughly the periodicity of rainfall over the country.

It is proposed to give here some account of the methods by which rules for river-stage predictions are derived.

Great rises to flood stages in a river usually result from a series of rain-storms, rather than from a single rainfall. When

a river is at a medium high stage, the result of long-continued rains, a great or even a moderate additional rainfall will carry it over its banks. It follows, from this, that no trustworthy estimates of coming floods can be formed for a river without river gauges. A single great downpour of rain does, however, occasionally carry a river to flood stage, as in the case of the Big Warrior, at Tuscaloosa, Alabama, March 25, 1881, when the river rose sixty-five feet in one night.

The rivers of the Great Lakes — the Niagara, the St. Lawrence, the Detroit, St. Clair, and St. Marie — are subject to very little




change year in and year out, varying only a few feet in stage. A greater rainfall than the average over the Lake drainage areas is simply stored up, raising the Lake surface, and causing a little higher stage of water than the average to prevail, lasting for a long time.

It is very different in the case of rivers formed by the union of a great number of small streams. When the rain falls, a large part of it goes almost instantly into the creeks and rivulets, forming the drainage system of the country. The water moves rapidly to a main drainage artery, causing its surface to rise

anywhere from one foot to thirty, or even, in exceptional cases, as much as sixty feet or more in a day.

The duration and rate of a rise has commonly a very close dependence on the area of country a river drains. For a river draining 500 or 600 square miles, a rise lasts but one day; for 7,000 square miles, three or four days; for 1,000,000 square miles, the rise may extend over two months or more. At the head waters of a stream a rise is usually small. The extent of the rise increases with the distance down stream to a maximum at a certain point, below which, to the sea, the oscillation between high and low water gradually diminishes to nothing.

Where the channel of a river becomes very wide the oscillation from low to high water diminishes. At Chattanooga, for instance, the range from low to high water is fifty-two feet; at Decatur, one hundred and sixty miles below, it is only twenty-six feet, and increases to fifty feet again at Johnsonville, two hundred miles below that. The range of stage at a place is a matter depending on the place, the area of cross-section, water surface slope, etc., and may be very different at places not more than one hundred miles apart.

Water flows along in the rivers under the action of gravity, like a ball rolling down an inclined plane. Some idea can be formed of the highest stages of water that will prevail at a place low down on a stream when the stages and rises are known at points farther up, judging from what is seen to have occurred in previous rises. This is the basis of river-stage predictions.

As a rule, observed rainfall is of very little use in predicting river stages. The amount of any rainfall that enters the ground is very uncertain, and varies at different times, depending on the rate of rainfall, and the permeability of the soil. The meteorological observing stations throughout the country, on the average, one hundred to one hundred and fifty miles apart, do not permit of forming a good estimate of the amount of water falling over a drainage area, which can be made of much service in predicting river stages.

Investigations are now under way with all the records of rainfall available, which, it is hoped, will show just what can be done with rainfall observations in the way of prediction.

The rate of travel of water in rivers is greater the greater the stage. In the Ohio River, for instance, the velocity varies from

two to four miles or more an hour. The rate of travel of a wave crest in the Ohio River does not differ materially from the rate of travel of the water, which is about eighty miles a day for medium and high stages. A slight retardation of wave crest occurs, as compared with the velocity of the water, due to the fact that the river channel has to be filled with water before a crest can occur.

The simplest case of river prediction is where there are two places on the same river without any relatively large amount of water coming into the stream from tributaries between them. At Cincinnati, for instance, and Evansville three hundred and sixteen miles below, the crest stages of various rises at the two places are compared. The corresponding crest stages are placed side by side, and arranged according to the magnitude of the stage at Cincinnati. The mean of all the corresponding stages at each place is taken extending over ranges of about five feet at Cincinnati. With the aid of a curve graphically, or by interpolation from the means, the corresponding Cincinnati and Evansville stages are derived for the exact five-feet stages at Cincinnati given in the following table. The average time of a wave crest from Cincinnati to Evansville is three days.

### Corresponding Crest-Wave River Stages.

| Cincinnati. | Evansville. (Three days later.) |
|---|---|
| 15 feet | 10.0 feet |
| 20 " | 14.4 " |
| 25 " | 19.4 " |
| 30 " | 24.0 " |
| 35 " | 28.6 " |
| 40 " | 32.8 " |
| 45 " | 37.0 " |
| 50 " | 41.2 " |
| 55 " | 44.6 " |
| 60 " | 47.0 " |
| 65 " | 48.0 " |

For a place where a rise in the river is due to a rise in two other rivers, as in the case of Pittsburg, at the junction of the Allegheny and Monongahela rivers, the crest-stages at Pittsburg corresponding to crests at Oil City, on the Allegheny, are obtained when there is little or no rise on the

Monongahela; also the crest stages at Pittsburg for crest stages at Confluence on the Youghiogheny when there is no rise at Oil City; and then for crests when there are rises at both places. These are combined in a table of double entry, from which, with the crests or stages at Oil City and Confluence, the stage at Pittsburg can be taken, which may be expected to occur in one or two days.

In the case of a rise in a river resulting from rises in several tributaries the quantities of water from which are relatively great as compared with that of the main stream, the method of predicting is different. A comparison of the Cincinnati crests, for instance, with those occurring afterward, at Cairo, will give very widely differing results in different cases.

At Cairo, a rise may be the result of a rise in the Upper Ohio, the Tennessee, Cumberland, Wabash, and Upper Mississippi, in any or all of them. The best method of procedure in this case was found to be by comparison of rises rather than by stages.

There are long records of stages at places on these rivers except on the Wabash. Rises are frequent, sometimes as the result of rises in some of the tributaries and again in others. There are records of stages at St. Louis on the Upper Mississippi, Cincinnati on the Ohio, Nashville on the Cumberland, and Chattanooga on the Tennessee rivers. There is very little known about the relative quantities of water passing these places for similar stages. A fifty-foot stage means probably a very different quantity of water passing at Chattanooga and Cincinnati. The quantity does not depend, either, on the amount of drainage area above the places. The area north of the Ohio River above Cincinnati is not very significant in the production of high water. The most important drainage is what comes from the mountainous region of western Pennsylvania and West Virginia.

The area of country drained by the Ohio River above Cincinnati is seventy-eight thousand square miles; by the Cumberland above Nashville about six thousand, and by the Tennessee above Chattanooga about twelve thousand.

The long record of stages and the numerous rises at Cairo, the result of rises sometimes in some of the tributaries and again in others, permits of partially disentangling the effects of

the rises in the various tributaries, and so forming some estimate of their effects separately.

When a rise of the river occurs at Cincinnati it ordinarily causes a rise six days later at Cairo. For a high stage of river at Cincinnati, the effect of a rise is greater on the Cairo stage than when the Cincinnati stage is low. For similar rises at Cincinnati, the effect on the Cairo stage is less the greater the stage at Cairo. The relation between the rises at a place as dependent on the stages is not known. It is assumed, in deriving prediction rules, that the effect of a rise is equal to the rise multiplied by the mean stage during the rise.

In seventy-six rises, the intervals between the crests at Cincinnati and Cairo were as follows: —

| | | |
|---|---|---|
| In | 1 case | 3 days. |
| " | 4 cases | 4 " |
| " | 5 " | 5 " |
| " | 41 " | 6 " |
| " | 9 " | 7 " |
| " | 5 " | 8 " |
| " | 3 " | 9 " |
| " | 4 " | 10 " |
| " | 2 " | 11 " |
| " | 1 case | 12 " |
| " | 1 " | 14 " |

The difference of wave-crest time in these cases is not due to actual differences in the velocity of the water at the different times, but to the different ways flood waves from the various tributaries are compounded in the main stream, owing to variety in distribution of the rainfall over the drainage area. The wave at Cairo is the resultant of the waves from the several tributaries, and not that of the Ohio River only.

The time of the crest at Cairo is always taken as six days after the Cincinnati crest, in making predictions. A sufficiently great number of rises have not been observed yet to determine the crest time with exactness as dependent on the rises and crests at the other places besides Cincinnati.

It is not a matter of great importance if the computed time of the crest is in error two or three days. The crest stages differ in most cases only a few tenths of a foot for two or three days on either side of the crest. The crests at Cairo are quite

flat, the stage nearest the high water usually lasting a considerable time.

The effect of a rise at St. Louis in producing a subsequent rise at Cairo was ascertained in the following manner: —

There is a river gauge at Paducah, Ky., on the Ohio River, about forty-six miles above Cairo, and just below the mouth of the Tennessee River. All the water draining from the Ohio valley passes Paducah. The Cairo gauge is about two miles above the junction of the Ohio with the Mississippi River. The lowest water at Paducah is about eighteen feet higher above sea level than the corresponding low water at Cairo. The records of water stages were examined for cases where there was little or no rise at Paducah for three days and there was some rise at Cairo during the same time.

In cases of this kind, the rises at Cairo must be due to the rises in the upper Mississippi River. The time of a crest stage from St. Louis to Cairo is taken as three days. The river stages at Cairo are practically as if it was located on the Mississippi River. In the case of a rise in the upper Mississippi, the back water amplitude as far up as Paducah is quite insignificant, and is therefore left out of account.

These special cases of rises at Cairo show that the rise at Cairo in three days, when the upper Ohio is not changing in stage, is equal to the preceding three-day rise at St. Louis, multiplied by the ratio of the Cairo to the St. Louis stage and by the factor 0.92.

The three-day change at St. Louis preceding the day of a crest stage at Cincinnati is considered as affecting the stage to subsequently occur at Cairo. The rises at Cairo were subjected to this modification previous to entering on the proceeding described for finding the relation of the Cairo to the Cincinnati rise. The rule for computing the Cairo rise is then as follows: —

The time of the river-water or crest-stage travel from Nashville to Cairo is taken as three days, and from Chattanooga to Cairo as six days. This is derived from a consideration of the relative distances as compared with the distance from Cairo to Cincinnati. This method was chosen in lieu of anything better. It is impossible to determine the time of crest travel from the interval between crest waves at Nashville and Chattanooga and

those following at Cairo, as the crests are complicated with those occurring about the same time at Cincinnati. The Cincinnati rise is the main and dominating cause of a rise at Cairo.

The relation of the rise at Cincinnati to the rises at Cairo, as dependent on the stage at Cairo, was derived from a comparison of the cases of great rises at Cincinnati with the subsequent rises at Cairo throughout all the range of stages in cases where there was comparatively little rise at Nashville or Chattanooga. The rises were so chosen as to have the rises at the two latter places relatively unimportant as compared with the Cincinnati rises. At the same time a plausible allowance was made for the slight rises at these places. In the case of rises at Cincinnati there is always some rise at these places.

By this proceeding, the factors given in the table below were obtained for certain average stages at Cairo. For the intermediate stages, they were obtained by interpolation. The factors express the relation between the weighted-mean rise at Cincinnati and the subsequent weighted rise at Cairo.

The same law is considered to hold for the Chattanooga and Nashville rise in relation to the Cairo rise as was found for Cincinnati. This, of course, may not be strictly true, but the assumption is the best that could be made under the circumstances.

Equations were formed, one for each of the seventy-six cases of rises at Cairo in which the Cairo weighted rise divided by the factor dependent on the stage was placed equal to the sum of the weighted rises at the three places — Cincinnati, Chattanooga, and Nashville — each multiplied by an unknown factor. By the weighted rise is meant the rise multiplied by the mean stage at a place during the rise.

Treating these equations by the method of least squares, forming normal equations and solving, the most probable values of the unknown factors were derived. The factors are, for Cincinnati 0.69, for Nashville 0.62, and for Chattanooga 0.42. They express the approximate relation of the six-day rise at Cincinnati, the three-day rise at Nashville, and the six-day rise at Chattanooga in producing a six-day rise at Cairo, subsequent to the occurrence of a Cincinnati crest.

In the case of a fall at any of the places instead of a rise, it entered the equation with the minus sign instead of plus.

When the river at Cincinnati has been rising for six days and has reached a crest, the rise at Cairo in the next six days will be equal to the rise at Cincinnati in the preceding six days multiplied by the mean stage at Cincinnati for the day of the crest and six days before and by the factor 0.69, plus the three-day rise at Nashville preceding the day of the Cincinnati crest multiplied by the mean stage at Nashville and by the factor 0.62, plus the six-day rise at Chattanooga in six days preceding the Cincinnati crest multiplied by the mean stage at Chattanooga and by the factor 0.42, the whole sum divided by the stage at Cairo and multiplied by a factor as given below, depending on the Cairo stage. To this is to be added 0.92 of the St. Louis rise in three days preceding the Cincinnati crest.

| Cairo stage. | Factor. |
|---|---|
| 20. feet | .353 |
| 25. " | .334 |
| 30. " | .308 |
| 35. " | .283 |
| 40. " | .237 |
| 45. " | .182 |
| 46. " | .171 |
| 57. " | .159 |
| 48. " | .150 |

For the first computation the stage at Cairo is taken as the stage on the day of the Cincinnati crest. With the rise computed in the manner described, the Cairo stage for the time six days ahead is known approximately. With the mean stage obtained from this, the computation is repeated and a more accurate value of the rise derived. Where there are falls at any of the places instead of rises, they have to be taken with a minus sign.

The probable error of a stage for Cairo, computed in this way is ± 1.4 feet; the probable error of the time is ± 1 day when the prediction is made for six days. The greatest error is six feet in seventy-six cases. The large errors are most apt to occur at the lower crests.

The uncertainty in the computed stage is due in part to the water coming into the river from the drainage area of 108,000 square miles below St. Louis, Cincinnati, Nashville, and Chattanooga, the water from which does not affect their gauge read-

ings. The drainage basins above Cincinnati, Nashville, and Chattanooga are shown on the map by the heavy dotted lines surrounding them. When the rainfall over the upper region is in excess of the average, the computed Cairo stage is too low; when less than the average the computed stage is too high.

At low stages the computed rises are not as accurate as at high stages. It sometimes happens that a rise occurs at Cairo without much of a rise at the gauges above, due almost wholly to rain in the lower part of the drainage area. The great stages at Cairo, however, never occur without very considerable rises at the upper gauges. Predictions of stages are only made for the high stages at Cairo.

These cases are typical of the various methods followed in deriving prediction rules for other places on rivers throughout the country.

The only case as yet where rainfall only is used in making a prediction is for the Savannah River, at Augusta, Ga. This river drains an area of about seven thousand five hundred square miles. A rise multiplied by the mean stage during the rise is nearly proportional to the average of the depth of rainfall at Atlanta and Augusta for the three days preceding the rise.

Some idea of a rise at a place can be formed by means of observations of river stages at the place alone. In the case of important rises approaching the flood stage, observations at short intervals give the means of establishing a rate of rise which can be used to compute a stage ahead by extrapolation. The variation observed in the rate of a rise is also useful in forming some idea of a coming stage. At Cincinnati, for instance, the important rises usually extend over at least six days. The mean daily rises as deduced from fifty-nine cases for the six days preceding a crest are: —

| | |
|---|---|
| 6th to 5th day . . . . . . . . | 2.2 feet. |
| 5th to 4th day . . . . . . . . | 3.2 " |
| 4th to 3d day . . . . . . . . | 3.8 " |
| 3d to 2d day . . . . . . . . . | 4.0 " |
| 2d to 1st day . . . . . . . . . | 2.8 " |
| 1st to crest . . . . . . . . . | 1.3 " |

When the rate of rise begins to diminish the crest is very likely not more than three days away.

The composite of a great number of cases of rises shows a

regularity which, however, in most instances the special cases do not show. On the whole, this is not a criterion of much value, except in a case where the drainage area above a place is very considerable, approximating 100,000 square miles.

At a point on a river with no gauge at any place on the river above it, a knowledge of a coming rise might be obtained from velocity measurements of the river current. A rise is preceded some considerable time by an increase in the velocity of the current caused by the increased head of water due to the rise at a point above without any change of stage. The rate of transmission of pressure through water is probably the same as that for sound through water, or about four thousand seven hundred feet a second, or more than one thousand times the velocity of the water current.

Very little has as yet been done anywhere in systematizing river predictions. France and the United States are the only countries where predictions are made. There is a rule for estimating the crest stage of flood waves in the Seine River, at Paris. The average of the rises at seven points on streams in or near the upper part of the catchment basin of the Seine multiplied by a constant gives the rise at Paris in the following three days. There is a different constant, whether the river at Paris is in a rising or a falling stage. The greatest error in a stage computed in this way for Paris is two feet.

On other rivers in France, the Loire and Garonne, the predictions are made with great accuracy by comparative crests or comparative rises.

The experience of the French engineers in deriving prediction rules for rivers with large tributaries has been that more satisfactory results are obtained by dealing with comparative rises rather than with stages. The same thing was found here before the work of the French engineers was known of, as described in the memoirs printed at the time of the Paris Exposition, in 1889. It would seem as if it would be possible to improve this class of river predictions if the relation of the quantity of water passing in the different tributary streams of a river for various stages was known. The French engineers, however, do not think favorably of the plan, and have not as yet succeeded in satisfactorily using discharge measurements to improve the rules for prediction.

It is confidently believed that in the case of the rivers in this country some improvement of predictions could be made if the river discharges were known. If the discharges were known, the product of rises by mean stage for the different stages could have appropriate factors applied to render them strictly comparable at different stages.

A large part of the uncertainty of a river-stage prediction is from the rainfall in the drainage area that comes into the river below the gauges relied upon in making the prediction, the water from which not passing the gauges has no effect on their readings. It is expected that some improvement can be made by means of the rainfall observations over these areas taken in connection with the up-river gauge readings. Investigations are now being made, with a view to introducing a correction to stage predictions based on the observations of the rainfall over these areas.

The fuller details of rules for river-stage predictions in the United States, as far as worked out, are given in Appendix No. 5 of the Report of the Chief Signal Officer, U. S. Army, for the year 1891.

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## THE FIRST SCIENTIFIC BALLOON VOYAGE.

R. DE. C. WARD.

THE interest that has lately been taken in balloon ascents in connection with meteorology, and the belief that in this way many of its problems that still remain unsolved may find their solution, has naturally turned attention towards ballooning for scientific purposes. Considerable has been written of early balloon ascents, and the credit of having made the first voyage of this kind has generally been given to Robinson and Lhoëst, who made an ascent in 1803. In a recent article,* however, Dr. Hellmann has shown that the credit does not belong to these men, but to Dr. John Jeffries, an American physician, born in Boston, and gives a short account of the first voyage which Dr. Jeffries made. Through the kindness of Dr. B. Joy Jeffries, of Boston, the writer has had access to many interesting records

* Zeitschrift f. Luftschiffahrt, January, 1892.

bearing on this remarkable event, and he believes that a brief account of this first scientific aerial voyage will not be unwelcome to the readers of the JOURNAL.

Dr. John Jeffries was born in Boston in 1744, his great grandfather, David Jeffries, having removed from England to Boston

in 1677, and his father, also David Jeffries, having been treasurer of the town of Boston for twenty-eight years before the Revolution. John Jeffries was graduated from Harvard College in 1763. He studied medicine with Dr. James Lloyd and went to England in 1768 in order to continue his studies there, returning to his native city again in 1769. He was a Loyalist, largely because of the friendships he had made in England, and was employed as surgeon in the military hospitals, receiving the commission of surgeon major. He spent ten years in London, from 1779 to 1789, as a successful practitioner, and it was during this time that his interest in ballooning began. As Dr. Jeffries said : "I wished to see the following points more clearly determined ;

first, the power of ascending or descending at pleasure while suspended and floating in the air; second, the effect which oars or wings might be made to produce towards the purpose, and in directing the course of the balloon; third, the state and temperature of the atmosphere at different heights from the earth; fourth, by observing the varying course of the currents of air or winds at certain elevations, to throw some new light on the theory of the winds in general."

The account of his two ascents Dr. Jeffries published in London in 1786, under the title of "A Narrative of the Two Aerial Voyages of Dr. Jeffries with Mons. Blanchard, with Meteorological Observations and Remarks," having first read the paper before the Royal Society in January of that same year. Speaking of the fact that former aeronauts had their principal attention "turned to ascertain the facility of an ascent," Dr. Jeffries goes on to say: "I became anxious to contribute my mite towards these important discoveries (temperature, air-currents, etc.), until by frequent revolving the subject in my mind, I resolved to gratify this, which had become my ruling passion." In order to fulfil his desire, Dr. Jeffries got acquainted with a Frenchman, M. Blanchard, who had already made four ascents, and paid him one hundred guineas for a seat on his fifth ascent, in England. The two men started on their trip at 2.38 P. M. on the 30th of November, 1784, from the Rhedarium, near Grosvenor Square, London, an immense crowd, including the Prince of Wales and the Duchess of Devonshire, witnessing the scene. Dr. Jeffries took up with him a thermometer, a barometer, a hydrometer, "one of Mr. Arnold's time-pieces," a pocket electrometer, and a mariner's compass, besides some phials with glass stoppers, which were to be opened at various heights and then corked up, in order to bring down samples of the air at different heights. The barometer was new, made for the purpose by Jones, of London, and was graduated down to eighteen inches. This instrument now hangs in the office of his grandson, Dr. B. Joy Jeffries, Boston.

The circumstances of the ascent do not seem to have been very favorable, for the writer remarks: "We were obliged to make our ascent from one of the most incommodious areas, or yards, for its extent, that is, perhaps, to be found in all London; and that on one of almost the shortest days in the year, amidst

the fogs and clouds of November." Dr. Jeffries' account of the rise of the balloon and of the view "of the greatest and most opulent city of the world" as the aeronauts passed over it, is very interesting, given in his quaint language. In about six minutes after they left the ground St. Paul's dome appeared like a bell suspended in the air, the lower part of the structure being lost in the fog, but soon the balloon rose above the "fogs and the clouds," some of which were "near and around it." The thermometer and barometer fell continuously, and at three minutes past three o'clock the former marked thirty-five degrees, having fallen from fifty-one degrees, and the barometer twenty-five inches, having fallen from thirty inches. Five minutes later the temperature was thirty-three degrees; the pressure twenty-four inches. The balloon soon rose into the clouds, and then M. Blanchard began to complain of the cold, and a little dog that had been taken up "began to shake and shed tears with the cold." At twenty minutes after three the thermometer stood at twenty-eight and one-half degrees, and the barometer at 21.25 inches, which were respectively the lowest temperature and pressure recorded. At twenty-three minutes past three "the balloon became quite distended and seemed to labour," so some gas was let out, and as they gradually descended they refreshed themselves with cold chicken and drank some wine to the health of their friends below.* The balloon descended with dangerous rapidity, and he says: "We then threw out everything except my instruments and our clothes," but in spite of the danger he did not forget to note the changes in the instruments. After several ineffectual attempts to catch the anchor in the trees on the ground as they came near it on the descent, they finally alighted at exactly fifty-nine minutes after three, in the parish of Stone, in Kent, having been "suspended and floating in the atmosphere one hour and twenty-one minutes."

* Some little social interest became attached to one bottle of this wine Dr. Jeffries carried up into the air. He brought it home with him to Boston, and Queen Victoria's father helped to drink it under the following circumstances. As Duke of Kent he was visiting Boston and was under the professional care of Dr. Jeffries. At that time Mr. Frederic von Geyer's daughter Nancy, a celebrated beauty, married Mr. Rufus Greene Amory. The Duke was present at the wedding, and by right of rank first kissed the bride, subsequently helping to dispose of the bottle of wine sent in honor of the occasion. Afterwards Dr. Jeffries' son, Dr. John Jeffries, married the daughter of Mr. Amory, the mother of the present Dr. B. Joy Jeffries.

As they landed, Dr. Jeffries says: "The neighboring inhabitants soon flocked about us, asking thousands of questions, and finding in the bottom of our aerial car a few bits of chicken and morsels of bread, I, at their request, divided it almost into atoms among them, every one being eager to get some of the food which they had seen literally descend from the clouds." "In the course of our descent," the writer goes on to say, "passing through a cloud or foggy vapour, the hydrometer, which had, during the course of our voyage, been gradually declining from o (where I had placed it at setting out), to five degrees dry, had when I examined it during our descent, changed to seven degrees moist. The electrometer, which I had repeatedly examined and attended to, I could never discover to be affected. The different heights of the mercury in the thermometer and barometer, and the state of the hydrometer, were taken and minuted with careful exactness."

The results of the ascent are given in the following table, which appears at the beginning of Dr. Jeffries' narrative: —

| Hours. | Minutes. | Therm. Degrees. | Barom. Inches. | Hydr. Degrees. | Electrometer. | |
|---|---|---|---|---|---|---|
| 2 | 20 | 51 | 30 | 0 | Though frequently attended to, I never observed to be any ways affected. | In the area of the Rhedarium. |
| 2 | 38 | – | – | – | | Was the minute of our ascension over the buildings around us. |
| 2 | 45 | 40 | 27 | 0 | | |
| 2 | 50 | 40 | 26 | 0 | | |
| 3 | 3 | 35 | 25 | 3 dry. | | |
| 3 | 8 | 33 | 24 | 0 | | |
| 3 | 13 | 31 | 23 | 4 dry. | | |
| 3 | 15 | 29 | 22½ | 0 | | |
| 3 | 17 | 0 | $21\frac{3}{10}$ | 0 | | |
| 3 | 19 | 28½ | 21.2½ | 0 | | |
| 3 | 20 | 0 | – | 5 dry. | | |
| 3 | 25 | 34 | 25½ | 0 | | |
| 3 | 45 | 40 | 27 | 7 moist. | | |

Near the end of his account Dr. Jeffries notes that, "Although our voyage was not distinguished by the length of time we were performing it, or the distance we went, yet I cannot but hope that the foregoing observations may be of some importance."

As the record of the first scientific balloon ascent ever made,

Dr. Jeffries' narative possesses peculiar interest, and it is certainly gratifying to Americans to know that to an American belongs the honor of having first planned and carried out such a voyage. In a later article it is intended to give an account of the first aerial voyage across the Channel, that having been accomplished by Dr. Jeffries in the year following his first ascent. The writer is indebted to Dr. B. Joy Jeffries for valuable criticism and suggestions, and also for the loan of the plate from which the accompanying portrait was printed. It represents Dr. John Jeffries in the car of his balloon, holding the barometer in his hand.

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## SNOW-STORMS AT CHICAGO.

A. B. CRANE, OBSERVER, WEATHER BUREAU.

THE writer, having been stationed at Chicago, Ill., during the year 1890–91, as an observer, had the opportunity of making the study of what he considers the most important weather feature in that locality during winter season, namely, heavy snow-storms. The past records were very carefully examined, and all data relating to the subject were tabulated, and have since been verified. The record begins with the year 1879, and includes the year 1890, — no heavy snow-storm having occurred in 1891 or thus far in 1892.

Twenty-five storms, all averaging a fall of four inches of snow or more, were found, and the following analysis was prepared: —

1. Location of "High" west of Lakes when snow began.
2. Location of "Low."
3. Temperature: Rise or fall at Chicago, twenty-four hours in advance of heavy snow.
4. Wind: Direction of about time and just before heavy snow began.
5. Wind: Do Lake winds occur in majority of cases of heavy snow-fall?
6. Does heavy snow occur most frequently with lows from the west, or from the Gulf?
7. Suspicion. Southerly winds necessary over the Mississippi valley twenty-four hours or more before heavy snow. Is it so?
8. Is temperature higher with the low having the heavy snow, or lower than the next previous low that passes?
9. Is barometer higher with the low having the heavy snow, or lower than the next previous low that passes?
10. About what temperature do the heaviest snows occur?

To be concise, and without discussing each storm individually, the following points of interest and importance are defined: —

(1) That twenty-four hours in advance of heavy snow-storms in the Upper Lake regions the area of high pressure is invariably in the northwest, and

(2) The low is to the south of west of Lake Michigan.

(3) The temperature before the heavy snow is quite low, *and nearly always* RISES; in some instances from zero, and below to nearly the freezing point (thirty-two degrees). The temperature rarely falls twenty-four hours in advance or during the storm.

(4) The winds at Chicago and vicinity are, before the storm commences, generally from a westerly quadrant, usually west and southwest (dependent upon the exact position of the low), and

(5) Blow *from* the Lake during or before the snow ceases, upon which it veers to the northwest, and generally with increased force, continuing for a day or two.

(6) Heavy snowfalls are most frequent from lows from the west; eighty per cent come up from the west, and the remaining twenty per cent from the Gulf, or other quarters.

(7) Investigation clearly indicates that southerly winds are necessary over the Mississippi valley twenty-four hours or more before very heavy snows or rain-storms (winter) occur, but for storms which originate in and are confined to the northern limit of the Southern States only. In some cases, however, southerly winds have prevailed over the Mississippi valley two or three days prior to beginning of snow-storm north; being a warm and moist wind it is therefore a "breeder" for the storm. It was thought that the southerly winds over the Mississippi valley were necessary for heavy snow-storms north, but they bear no significance, and generally, while a severe snow-storm is raging over the Lakes, the winds in the Mississippi valley are variable.

(8) As a rule, the temperature is higher with the low having the heavy snow, because it rises considerably before the snow commences. The next succeeding low has about as low a temperature originally, but does not rise so much as with the low having the snow. The dry low is, therefore, colder.

(9) No decided answer can be given, as the barometric conditions are about evenly distributed, and heavy snow-storms are as

frequent with, or rather preceded by, as many highs as are produced by lows, but when the storm sets in with the falling pressure it remains longer, retarding, as it were, but the amount of snowfall is not, as a rule, so great as when preceded by a moderate high.

(10) The heaviest snows occur with temperature ranging from twenty-five to thirty-two degrees, although heavy snow-storms have set in with a much lower temperature (see storm of Feb. 2, 3, 1883); but always will it be seen that the temperature rises considerably, and the mean temperature rarely remains below twenty degrees for the coldest.

The theories here advanced are not intended to be considered infallible and a sure source of prognostication of heavy snow-storms, but rather to bring to notice those meteorological characteristics which prevail prior to and during the heavy snow. It is only by investigation and study of the elements that the truth will be learned, and meteorology, as a practical science, advanced to that full measure of perfection and usefulness of which it is unquestionably susceptible. That the weather is capricious and extremely difficult to correctly forecast at times is surely a fact beyond peradventure, and cannot be worked out mathematically with set and prescribed rules, but we can get at the root of the science and gradually build step by step until a final ultimatum is reached. Thus we may traverse a crowded thoroughfare, such as Broadway, or the boulevards of Paris, and never see any two faces alike, but yet there is no difficulty to distinguish the race features. So it is with storm areas — hardly any two exactly alike, but still all bearing a similarity, to a certain extent.

*January.* — Using the twenty-five snow-storms (which were tabulated in an approved manner) as a basis of comparison, it is found that heavy falls of snow occur most frequently in the month of January; out of twenty-five snow-storms, ten, or forty per cent, occurred.

The mean temperature of the ten storms, 21.4 degrees. The largest amount, twelve inches, occurred on Jan. 18–21, 1886, with mean temperature, nineteen degrees. This storm was preceded by moderate high followed by moderate low barometer, and with sudden and decided falling temperature followed by rising, fifteen degrees preceding to thirty-four de-

grees during storm. The area of high pressure was central over Manitoba, and the low area central in the middle slope.

*February.* — For the month of February, we find six heavy snowfalls, or twenty-four per cent. Mean temperature of the six storms, 23.5 degrees. Largest amount, fifteen inches, on 4–9, 1885. This storm came in with a well-developed low which hung around Lake Michigan a few days before snow began ; mean temperature during storm, twenty-three degrees, but rose to thirty-two degrees. Area of high pressure not well defined, but small high in Northern Montana. Location of low, Kansas.

*March.* — In March we find four heavy snow-storms, or sixteen per cent. Mean temperature during storms, 32.2. Largest amount, fourteen inches, on 19–20, 1881 ; mean temperature during storm, thirty-three degrees. This storm came up from the Gulf. Area of high over Arizona, low over Indian Territory and Arkansas.

*April.* — We find, too, that the spring months do not escape the heavy snows; one, in particular, occurred on April 11, 12, 1881, with a total of nine inches, which, however, might properly be classified as a "sleet storm." The mean temperature during this storm, thirty-five degrees, is considerably higher than any of the twenty-five, except one, which occurred on the last day of March, 1886, with the same mean thirty-five degrees. Area of high in North Dakota, low in Colorado.

*December.* — Christmas month divides even honors with March in number of storms, but not in quantity. The December storms are not attended by so heavy a fall of snow as the other wintry months. The largest amount, nine inches, occurred on the 12–14, 1885, with mean temperature twenty-three degrees. This storm came in with a high, which accounts for its having a lower mean temperature than would be expected.

To sum up, then, we find that (1) January is the banner month for heavy snow-storms, followed, next in order, by February ; (2) that the largest amounts occur in February, and the next largest in March ; (3) that the mean temperature during the storms is coldest in January, and warmest in March and April.

PHILADELPHIA, March 4, 1892.

# No. 6.—THE EYE OF THE STORM.

SIDNEY M. BALLOU.

1. *Conclusions.*
2. *Selected descriptions.*
3. *Classification of facts.*
   Place of occurrence.
   Wind before centre.
   Passage into the centre.
   Wind in the centre.
   Sky in the centre.
   Birds, etc., in the centre.
   Temperature during the calm.
   Barometer during the calm.
   Dimensions of the calm.
4. *Discussion of Meteorological phenomena.*
   Espy's theory.
   Descensional movement.
   Other explanations.
   Cause of descent.
5. *Need of more observations.*

It is a well-known fact in meteorology that in the centre of the most violent hurricanes there is an area of very light winds, or absolute calm. Over this area the torrential rain of the hurricane ceases, and the clouds frequently break away, showing blue sky, with the sun, or the moon and stars. On account of its peculiar clearness this spot has received the name, "eye of the storm."

## CONCLUSIONS.

For the convenience of the reader the following summary is made of the features of this calm centre, each of which will be treated more fully hereafter.

The eye of the storm is a calm area, commonly ten to twenty miles in diameter, characteristic only of the most violent class of tropical cyclones. Just about the centre of these cyclones the wind is indescribably furious, and the rain falls in torrents; yet the passage into the calm is a matter of a few minutes. The eye is sometimes an area of light breezes, but more commonly of absolute calm, without rain, and often with blue sky. The cross sea, however, is very violent and dangerous. Birds and sometimes butterflies have been found in the centre, usually in an exhausted state.

Thermometric and barometric observations in the centre are meagre and contradictory, and the meteorological conditions not well understood. There appears, however, to be sufficient evidence of a gradual settling of air over the calm area, the

probable cause of which is the withdrawal of air by friction with the revolving circle of winds. There is great need of further observations of the significant meteorological phenomena.

SELECTED DESCRIPTIONS.

In this paper will be given the accounts of some of the observers who have passed through the eye of the storm, a collection of the significant facts concerning it, and a review of the different explanations of the occurrences which have from time to time been offered.

There are some early accounts of such a calm. Capt. William Dampier, in his quaint old "Voyages and Descriptions," of which a fifth edition was printed in 1705, tells, "from the relation of Mr. John Smallbone," the following incident, which occurred at the island of "Antego"—probably Antigua — in August, 1681 :*

"And about 7 a Clock that evening that the storm came, he (Capt. Gadbury) dreading it, went ashore with all his Men, and retired into a poor Planter's House about half a mile from the shore. By that time he and his Men were arrived at the House, which was before 8 a Clock, the Wind came on very fierce at N. E. and veering about to the N. and N. W. settled there, bringing with it very violent Rains. Thus it continued for about four hours, and then fell flat calm, and the Rain ceased.

"In this Calm he sent 3 or 4 of his Men down to the Cove to see what condition the Ship was in, and they found her driven ashore dry on the Sand, lying on the one side, with the Head of her Mast sticking into the Sand; after they had walked round her and view'd her a while they returned again to the Capt. to give him an Account of the Disaster, and made as much haste as they could, because the Wind began to blow hard at S. W., and it blew so violently before they recover'd the House, that the Boughs of the Trees whipt them sufficiently before they got thither, and it rained as hard as before. The little House could scarce shelter them from the wet; for there was little beside the Walls standing: For the 1st Northerly Gust blew away great part of the Ridg and most of the Thath."

Here we may note three points: a hurricane veering from northeast to northwest, a calm interval, and a recommencement of the violent wind, from southwest. In 1687, while in the China

* Voyages and Descriptions. By Capt. William Dampier, Vol. II., Part 3. London, 1705, 69.

sea, Captain Dampier himself experienced a calm of this sort, as he relates in another volume.*

"The Day ensuing, which was the 4th day of July, about 4 a Clock in the afternoon, the Wind came to the N. E. and freshened upon us, and the black Clouds began to rise apace and mov'd towards us, having hung all the morning in the Horizon. By 12 a Clock at night it blew exceeding hard, and the Rain poured down as through a Sieve. The violent Wind raised the Sea presently to a great heighth, and it ran very short and began to break in on our Deck. We were forced to put right before the Wind.

"We continued scudding right before Wind and Sea from 2 till 7 a Clock in the Morning, and then the Wind being much abated, we set our Mizen again, and brought our Ship to the Wind, and lay under a Mizen until 11. Then it fell flat calm, and it continued so for about 2 Hours; but the Sky looked very black and rueful, especially in the S. W., and the Sea tossed about us like an Egg-shell, for want of Wind. About one a Clock in the Afternoon the Wind sprung up at S. W. out of the quarter from whence we did expect it: therefore, we presently brail'd up our Mizen, and wore our Ship; but we had no sooner put our Ship before the Wind but it blew a Storm again, and it rain'd very hard, though not so violently as the Night before: but the wind was altogether as boysterous, and so continued till 10 or 11 a Clock at Night. All which time we scudded, or run before the Wind very swift, tho' only with our bare Poles, that is, without any Sail abroad. Afterwards the Wind died away by degrees, and before Day we had but little Wind, and fine clear Weather."

Again in this account we have the calm interval in a hurricane, the shift of wind, this time from northeast to southwest, and, in addition, a statement of the condition of the sea. During the hurricane it "ran very short, and began to break in on our deck," while in the calm interval it "tossed us about like an egg-shell."

It may be remarked that to Dampier there seemed nothing extraordinary in the occurrence of a calm in the middle of a hurricane. At a time when meteorological phenomena were still unexplained and without any known relations to each other, a fact like this was no more remarkable than many others. Even a hundred years later, when Capper was trying to explain the

*A New Voyage round the World. By Captain William Dampier, Fifth Edition, London, 1703. Vol I., 413.

origin of storms, he makes no comment upon a similar happening, at Pondicherry, Dec. 30, 1760, * which he gives as follows:

"Towards the evening, however, the wind freshened from the northwest, and at eight at night encreased considerably. About midnight the wind veered round to the northeast, fell calm with a thick haze, and in a few minutes after flew round to the southeast, whence it blew with great violence."

When in the present century, Thom, Reid, Piddington, and Redfield began to collect data for their investigation of storms, they found many instances of the calm and the accompanying shift of wind in a hurricane. One which was often quoted was that of the "Exmouth," which in the midst of a terrific storm had, as related in the log, the following experience: †

"At 11 h. 30 m. [May 4, 1840], we had a most tremendous squall, which continued only for a few minutes, and then lulled away into a perfect calm.

"Noon. Calm.

"P. M. Calm still continued, and a most awful silence prevailed; ship tumbling about in the trough of the sea quite ungovernable, and the sea making a fair breach over us. At this moment the quicksilver disappeared in the tube of the barometer, which Capt. Warren supposed was caused by some injury it had received, or that we should have a return of the hurricane with greater violence.

"At 12 h. 20 m. the sun made its appearance for a few minutes, and then disappeared, followed by an awfully hollow and distant rumbling noise. In a few minutes we received a most terrific gust from the south-southeast, laying the ship completely on her beam ends, blowing away the fore-topsail yard; weather quarter-boat torn from her lashings, and flying over lee quarter in several pieces.

"At 8 P. M. the quicksilver rose in the tube of the barometer to 29.00 as suddenly as it fell."

The calm had now come to be recognized as the central point of a revolving and advancing storm, around which the wind was blowing in a more or less complete circle. The difference in direction of wind at the ends of any chord of the circle accounted for the shift of wind experienced at any place over which the centre passed.

* Observations on the Winds and Monsoons. James Capper, London, 1801.

† Alexander Thom: An Inquiry into the Nature and Course of Storms, etc. London, 1845, 94.

Later descriptions, therefore, are given in terms accordant with this theory. Five detailed accounts have been selected, as covering the most significant facts. The first instance is that of a tug in the Calcutta cyclone of 1864.*

"The "Alexandra" steam tug was at anchor off Sangor Lighthouse on the early morning of the 5th. At 4 A. M. the wind shifted suddenly to northeast, blowing in furious gusts, accompanied by pelting sleet and seas over all. On coming head to wind the engines were set going at full power; about 8 or 9 A. M. it became suddenly calm, with a heavy confused sea, the sun appearing at the turn for a few minutes. The calm interval lasted about three quarters of an hour, the steamer's head to wind and the engines doing their best. During the calm, being apparently in the vortex of the hurricane, several land birds were falling about the decks, — some dead. At the end of the calm, a thick mist and heavy rollers seemed coming from northwest, accompanied by a moaning sound, which was immediately followed by a sudden blast from the northwest, throwing the steamer on her beam ends, and burying her in a sheet of foam to the top of the funnel."

Next may be quoted a centre passage of the ship "Idaho," in a hurricane in the China Sea, Sept. 21, 1869. The passage is from a very vivid account of the storm by Medical Director Albert L. Gihon, U. S. N.†

"Suddenly the mercury rose [from 27.62] to 27.90, and with one wild, unearthly, soul-thrilling shriek the wind as suddenly dropped to a calm, and those who had been in these seas before knew that we were in the terrible vortex of the typhoon, the dreaded centre of the whirlwind.

"Till then the sea had been beaten down by the wind, and only boarded the vessel when she became completely unmanageable; but now the waters, relieved from all restraint, rose in their own might. Ghastly gleams of lightning revealed them piled up on every side in rough, pyramidal masses, mountain high, — the revolving circle of wind, which everywhere inclosed them, causing them to boil and tumble as though they were being stirred in some mighty caldron. The ship, no longer blown over on her side, rolled and pitched, and was tossed about like a cork. The sea rose, toppled over, and fell with crushing

* Gastrell and Blanford: Report on the Calcutta Cyclone of the 5th October, 1864. Calcutta, 1866, 28.

† Gihon: "A Night in a Typhoon." The United Service, Vol. X., No. 4, April, 1884, 364.

force upon her decks. Once she shipped immense bodies of water over both bows, both quarters, and the starboard gangway at the same moment. Her seams opened fore and aft. Both above and below, men were pitched about the decks, and many of them injured.

"At twenty minutes before eight o'clock the vessel entered the vortex ; at twenty minutes past nine o'clock it had passed and the hurricane returned, blowing with renewed violence from the north, veering to the west. The ship was now only an unmanageable wreck."

The third account is from the log of steamship "Inchulva," in the Arabian Sea, May 29, 1881.*

"We consider ourselves in the northwest quadrant, with the centre coming up from the southeast so fast there is no time to dodge it. So we prepare for this dreaded centre to pass over us. The wind increases much, as it advances. The sea cannot rise. We notice the most from the east and southeast. Noon : a terrific wind still at northeast, steady. Away goes fore-gaff and fore-trysail, hatches, in fact everything the wind can reach blows to atoms. 2 P. M., the centre passes over us. During this time it is calm, with a fearful boiling sea. The clouds hang heavy to the southwest. Sun's limb clearly visible through thin yellowish haze ; also several stars, at least a dozen. 2.40 P. M., wind light from southwest ; in a few minutes the cyclone has increased in force to a greater extent than that part of the storm at northeast ; rain falls in torrents. During the time the centre was passing over us the barometer fell until the hand came against the tube of the thermometer, so could fall no more. We see many land birds and butterflies and whales in the centre. We employ ourselves during the calm interval clearing up the wreck and getting on hatches. As soon as the wind goes to southwest, the barometer rises and continues so to do as the centre passes away from us."

A centre passage of considerable meteorological importance, on account of the observations taken, was that at Manila, Oct. 20, 1882. The following extract † gives the facts relating to the calm itself : —

"*Vortex.* — At 11.46 A. M. (20th), after a violent rush from the west-northwest, Manila was in the vortex. The calm was not absolute, but with alternate gusts and lulls for about eight min-

* Indian Met. Memoirs, Vol. IV., Pt. 5; Calcutta, 1888, 308.

† Kneeland: The Typhoon at Manila, Philippine Islands, Science, Vol. I., No. 1, February, 1883, 8.

utes. At 11.52 the calm was absolute for two minutes; then alternate calm and gusts from the southwest. Blue sky was not seen, but it cleared to a dense, watery vapor; the dark belt of the storm could be traced on the horizon. The diameter of the vortex was probably not more than fourteen or sixteen miles.

"*Changes.* — The most striking phenomenon was the sudden change of temperature and hygrometric condition of the air, as revealed by the curves traced; the former from seventy-five degrees to eighty-eight degrees Fahrenheit [*i. e.*, seventy-five degrees before passage of centre, eighty-eight degrees during passage, and seventy-five after], and the latter from fifty-three (rarely observed here, and only in April and May, up to saturation [*i. e.*, saturation before and after passage, fifty-three during passage]. Persons who opened their windows during the calm were instantly compelled to close them, for the air 'burned' as in the Italian sirocco."

Last of all we have a recent report by Capt. P. Duhme, steamship "Taicheong," in a hurricane off Formosa, July 17, 1891.*

"In order to avoid running straight into the centre I had the ship headed northeast into the prevailing sea, which manœuvre was executed without accident. At 11.15 P. M., the barometer having fallen to 726.2 mm. (reduced), the wind suddenly moderated and backed to north-northwest, the sky cleared, the moon and stars becoming visible; a few sea birds anxiously fluttered about the ship. Until twelve o'clock there was a gentle northwest breeze, the barometer having fallen 0.6 mm. more, then the smoke from the smoke pipe was suddenly driven from southwest. The engine having worked slowly only for some time, I immediately rang full speed and brought the ship's head to southwest. The wind increased rapidly from southwest, the barometer rose, and about fifteen minutes after the almost calm region had passed the ship, the southwest wind was blowing with indescribable violence. Under full power the ship headed southwest by south in comparative comfort and escaped all damage. The southwest wind decreased slowly."

These descriptions give a general idea of the centre passage of a hurricane on land and sea. We shall now proceed to classify the facts from these and other sources, in order to obtain an accurate knowledge of the phenomena to be explained.

## CLASSIFICATION OF FACTS.

*Place of occurrence.* — The central calm is most characteristic of tropical cyclones. It has seldom been reported from cy-

* Seeman: "Hansa," No. 38, 1891, 615.

clones originating in temperate latitudes. Cyclones originating within the tropics may, however, move poleward into the temperate zones carrying their characteristic centre with them. Centre passages have been reported as far north as New York, as the case of the "Charles H. Marshall" in the March blizzard of 1888.* One of the first storms investigated by Redfield † apparently gave a centre passage in Connecticut.

*Wind before centre passage.* — As the storm centre moves towards the observer, the wind is steady in direction, blowing nearly at right angles to the path of the storm. There is a heavy rain, usually accompanied by lightning and thunder. Just before the passage of the central calm the hurricane is at its height. Captains of vessels report the wind as indescribably furious. Everything on deck the wind can reach is blown to pieces. In several instances the boat at the weather davits has been torn from strong fastenings and carried clear over the ship. In short, we have reports of winds as severe as any vessel could live through ; and beyond that we can only conjecture, from the great number of ships "last seen" near the storm centre, how much more violent the hurricane may be.

*Passage into the centre.* — In the majority of cases reported the ship passes almost instantaneously from the most frightful hurricane into an absolute calm. Thus the captain of the French frigate "Bridet" reports : ‡ "La tempête s'est apaisée d'une façon si brusque, que nous passons sans transition des craintes les plus vives à la sécurité la plus complète. Le temps s'emblit, la pluie cesse." Occasionally, however, after the first abrupt lull, the wind dies away gradually, so that it may be ten minutes or more before there is a perfect calm.

*Wind in the centre.* — The calm is usually described as complete. Making all allowance for effect of the contrast with the preceding gale, there seems no reason to suppose that, in most cases, there is any appreciable motion of the air. The captain of the "Bridet" states : ‡ "Le calme le plus compléte permettait de tenir sur le pont une bougie allumée," and on another occa-

* Hayden: W. I. hurricanes and the March blizzard, 1888; N. Y., 1889, 24

† Redfield: Storms of the Atlantic Coast, Amer. Jour. Sci. and Arts, XX., No. 1, 20.

‡ Davy: Les Mouvements de l'Atmosphère. Paris, 1877, 238.

sion Commander Dix, of R. M. S. "Mersey," says :* "I believe a candle would have burnt in the open air."

On the other hand there is a number of cases reported either of light winds, or, as in the Manila typhoon, of alternate gusts and lulls.

*Sea in the centre.* — From Dr. Gihon's account, it will be seen that the calm centre is no haven of rest for such ships as may be in the hurricane. It is true that they escape the fury of the wind, but only to lie at the mercy of a fearful cross sea.

Reports speak of it as "a high cross sea, rising perpendicularly," † or as a sea "run up in the shape of a cone, making it very dangerous for a ship to live in." ‡ Sometimes, as in Dr. Gihon's report, the waves break upon the vessel from all sides at once, § or as in the case of the "Exmouth," the sea makes a fair breach over the helpless ship.

*Sky in the centre.* — Three of the descriptions given in detail, those of the "Exmouth," "Alexandra," and "Inchulva," mention the fact of the sun being seen during the central passage, while at Pondicherry and Manila there was still a thick haze. The clearing of the sky overhead, either wholly or partially, is one of the most marked feature of the centre. The heavy rain of the hurricane ceases, and the sky clears either to blue sky with the sun or stars visible, or to a haze. Some characteristic reports are as follows: "A lull, the weather cleared up, with clear sky overhead, but round the horizon all dark." ||

"The sun shone at intervals during the calm." ¶

"The wind suddenly moderated and backed to north-northwest, the sky cleared, the moon and stars becoming visible." **

"The appearance of the sky was very remarkable. In the zenith the haze was so thick that the direction of the scud could not be determined, but to the east and northeast it was slowly

* Met. Data for the Nine 10° Squares; London 1876, 92.

† Ship "Krishna," Piddington, 1st Mem. Jour. As. Soc. Bengal, Vol. IX., 568.

‡ "Ann Metcalf," October, 1842; Piddington, 8th memoir, Jour. As. Soc. Bengal, XII., 344.

§ Similar cases are reported by Shück, Die Wirbelstürme, 1881, 53, and by Piddington, Jour. As. Soc. Bengal, XIV., Pt. 2, 711.

|| Ind. Met. Mem. IV., Pt. 2, 101.

¶ Gastrell and Blanford: Calcutta cyclone, Calcutta, 1866; Appendix, 39.

** Steamship "Taicheong" off Formosa, July 17, 1891. Capt. S. H. Seeman: "Hansa," No. 38, 1891, 615.

moving, as before, to the west and southwest, while in the south from thick, heavy masses of clouds, the scud was rising and flying to the north and northeast."*

"The clouds in the zenith appeared to be revolving rapidly; there was a little lightning, but no thunder. At 7.30 the clouds in the zenith rose, and the stars appeared, while banks of clouds remained all round the horizon in heavy, dense masses." †

*Birds, etc., in the centre.* — There have been several reports of an unusual number of birds in the eye of the storm. The log of the "Inchulva," already quoted, says: "We see many land birds and butterflies and whales in the centre"; and that of the "Alexandra": "Several land birds were falling about the decks, some dead." Other log books read: "A few sea birds anxiously fluttered about the ship." ‡ "During the calm, ship covered with aquatic birds, thousands of them dying on deck." § "The ship became inundated with a number of beautiful butterflies, while many species of sea birds crowded the deck." ||

"At 9 A. M. it suddenly fell a dead calm. A large number of birds of the Petrel genus alighted on board, and took shelter in boats and under hencoops." ¶

*Temperature during calm.* — Of the temperature of the eye of the storm we have very insufficient data. It is true that at Manila there was a thermograph, the curve of which showed a rise from 75° F. to 88° F., so that "the air 'burned' as in the Italian sirocco." One other observer of a centre passage on land remarks that "the atmosphere was most oppressive." ** But, curiously enough, not one of the many reports from vessels which I have seen makes mention of any increase in temperature. On the contrary a recent storm log †† which gives accu-

* Piddington: Horn Book, N. Y., 1848, 162.

† Buchan: Handy Book of Meteorology, 2nd Ed., Edinburgh and London, 1848, 271.

‡ Steamship "Taicheong," off Formosa, July, 1891. Seeman: "Hansa" No. 38, 1891, 615.

§ Ship "Buckinghamshire," Arabian Sea, April, 1847. Piddington: 15th Mem., Jour. As. Soc. Bengal, XVII., 30.

|| Ship "Typhoon," Arabian Sea, June, 1859. Dallas, Cyclone Mem. IV.

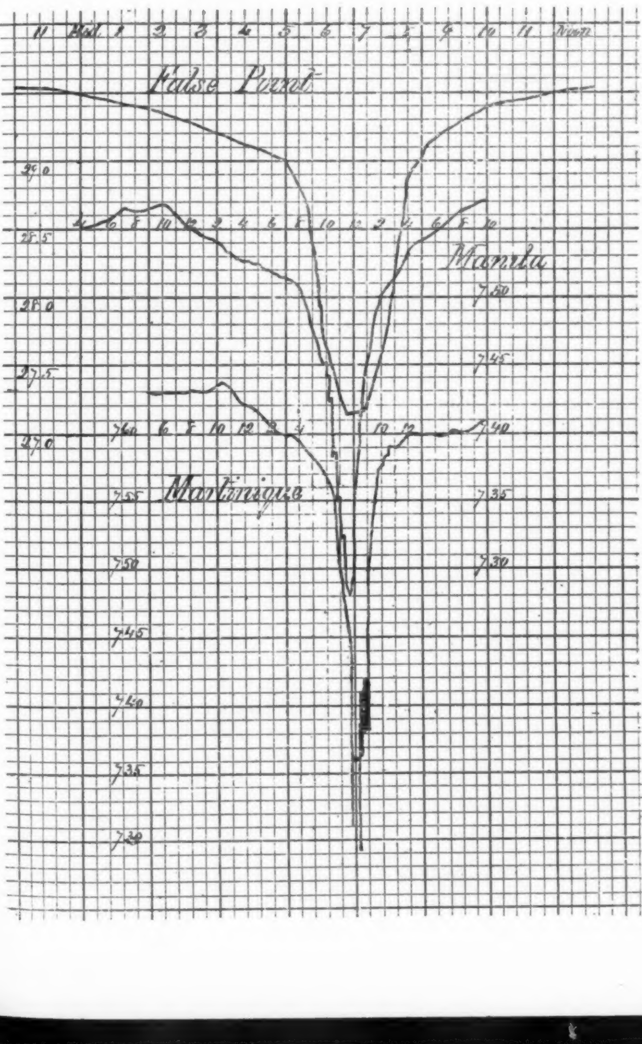
¶ Ship "Whitby," October, 1842. Piddington: 8th Mem. Jour. As. Soc. Bengal, XII., 342.

** Buchan: Handy Book of Meteorology. 2nd Ed., Edinburgh and London, 1848, 271.

†† Steamship "Weimer," Oct. 5, 1891. U. S. Hydrographic Office. Unpublished.

rate barometric observations reports both wet and dry bulb thermometers steady at 22° C., the sky being overcast.

*Barometer during calm.* — All reports agree that the calm centre is, roughly speaking, the lowest point of barometric depression in the hurricane. As to how the barometer varies during the interval of the calm passage, the accounts are meagre and more contradictory. Most captains read the barometer every half hour or hour, and the one reading in or near the calm does not give much information on the subject. In many cases, however, the barometer has been kept throughout the calm, and these cases I shall quote in detail.



There are three cases on record in which the calm centre has passed over a self-recording barograph. The resulting records are given in the diagram, each on its own scale. The following reports accompany the barographs : —

(1) False Point, India, Sept. 22, 1885*: ". . . 6.30 A. M. hurricane still blowing, but wind hauled to N. W., when it suddenly lulled, and became almost a calm ; 6.50 the wind had shifted to the W. S. W., and blew again with redoubled force, the gusts being most terrific. At 7 A. M. the barometer began to rise again rapidly."

(2) Manila, Philippine Islands, Oct. 20, 1882.† "The lowest barometer was at 11.40, or six minutes before entering the relative, and 10-12 before the absolute calm ; at this time Manila was probably the nearest to the centre of the vortex. At 11.54 it began to rise rapidly, the wind changing suddenly to the southwest, but with equal violence. The blow lasted two and one half hours, and its traced fury for the last half of the diagram was estimated, but not observed for want of instruments."

(3) St. Pierre, Martinique, Aug. 18, 1891.‡ "From 8.10 to 8.40 P. M. this barometer vibrated excessively, but a good aneroid, which I observed, recorded very well every difference of pressure, and the passage of the centre over St. Pierre was clearly marked at 736 mm. The other minima (due to rapid oscillations varying in time from two or three seconds to two or three minutes), indicating clearly the passage of secondary whirls, rendered evident by the terrific noise of tiles and broken roofs ; this fact was corroborated on the following day by the appearance of certain broken trees which could not have been bent in the way they were except by a strong gyratory movement. Moreover, in certain places in the country there were long paths or lanes where the destruction was greater than elsewhere."

At False Point, then, the barometer was lowest at the beginning of the calm ; it rose slowly throughout the calm, and for ten minutes after the hurricane recommenced, then rose rapidly. At Manila it was lowest before the wind died away, and appar-

* Ind. Met. Mem., Vol. IV., Pt. 2, 102.

† Kneeland : Science, Vol. I., No. 1, 1883, 8.

‡ Report by Mr. Léon Sully, Pilot Chart of North Atlantic, October, 1891.

ently steady until its sudden rise at the end of the absolute calm. At St. Pierre it was steady throughout the calm.

A number of verbal accounts, showing the behavior of the barometer during the calm, show a great diversity. To begin with the least frequent, there is but one report of an increase of pressure during the calm. That is given by the ship "Star Republic," * in 1844.

(4) "At the time of the lull the barometer stood at 28.10 [corr. 28.24], when it rose rapidly three-tenths in thirty minutes [the duration of the calm], and then remained stationary for two hours, rising again as the gale abated."

(5) Together with this may be placed the account of the "Idaho," which has been quoted in detail: "Suddenly the mercury rose [from 27.62] to 27.90 and the wind as suddenly dropped to a calm."

There are three accounts of the barometer remaining perfectly stationary during the calm, so that a plotted curve of the pressure would have a flat base. The Norwegian bark "Dione" † reports: (6) "At 4 A. M. the barometer showed 730, and at 6 A. M. the very lowest during the hurricane, namely 728. Then a change came. The wind suddenly lulled considerably and at one time almost died away, while the sea became more confused than ever, causing the vessel to labour heavily. After the lapse of three quarters of an hour the barometer rose 12 mm. almost instantaneously, whereupon the wind suddenly commenced to blow from the south-southeast with nearly equal strength as before."

The second example is that of the station of Contai,‡ India: (7) "Between eight and quarter to ten the barometer (aneroid) fell from 28.95 to 28.025, at which point it remained till eleven, during which the centre of the cyclone was passing over the station."

(8) The third is that of the "Bridet" § which reports that during the calm the barometer remained steady at 740 mm.

* Redfield: Hurricanes and Northers, New Haven, 1846, 48.

† Hayden: W. I. Hurricanes and the March Blizzard, 1888. N. Y., 1889. Plate IX.

‡ Gastrell and Blanford: Calcutta Cyclone of October, 1864, Calcutta, 1866, 30.

§ Davy: Les Mouvements de l'Atmosphère, Paris, 1877, 238.

Still another peculiarity is indicated by the report of the ship "Britannia," * in the False Point cyclone of September, 1885 :

(9) "At about 3 A. M. calm for about half an hour; the aneroid much agitated during the calm. One hour after the shift of the wind the barometer began to rise."

Next we have a number of different reports, all of which seem to indicate that the pressure continued to fall during the calm interval.

In the first of these, No. 10, the barometer did not rise again until two hours after the centre had passed. In Nos. 11, 12, 13, the rise was coincident with the end of the calm; in No. 14, it was in the middle of the calm, and in Nos. 15, 16, 17, the time of lowest pressure is not given.

(10) Pondicherry, Oct. 23, 1842 :† "At the moment that the storm suddenly shifted to the south and southeast, the barometer had attained its lowest point of depression, the mercury having fallen to twenty-eight inches. It was at 8.30 P. M. that the mercury began to rise again."

(11) In 1871, at St. Thomas, Capt. Dix, of R. M. S. "Mersey," detailed an officer to watch the barometer throughout the hurricane, — an example much to be commended. In Capt. Dix's report he says : — ‡

"The calm lasted from 5 P. M. to 5.35 P. M. At 5.25 P. M. the barometer reached its lowest point, 28.62. At 5.35 P. M. as I saw the ripple of the southerly gale coming along the water, the officer stationed by the barometer called out, 'The barometer is rising, sir,' and directly the wind struck us it began to rise fast."

(12) The report from the "Booldana," in the False Point cyclone of 1885,§ though meagre, indicates a similar occurrence, for the lowest barometer was at 7 A. M. of Sept. 22, which is the time that the gale broke upon the vessel after the calm.

(13) In the report of the "Taicheong," already given, the barometer fell 0.6 mm. during the calm and rose as the steamer again entered the hurricane.

(14) Blanford || gives a plotted curve for the Midnapore

* Indian Met. Mem., Vol. IV., Pt. 2, 100.

† Piddington: 8th Mem. Jour. As. Soc., Vol. XII., 363.

‡ Met. Data for the Nine 10° squares, London, 1876, 92.

§ Ind. Met. Mem., Vol. IV., Pt. 2, 101.

|| Climates and Weather of India, London, 1889, 238.

cyclone of 1874, in which the lowest point of pressure is at about the centre of the calm.

Next we have the three reports in which the exact time of lowest pressure is indeterminable. The first * is that given by the captain of the "Harkura": —

(15) "During the lull, when we were in the vortex, the barometer, a standard one by Shepherd, of London, stood at 27.50; afterwards [in lull] reported to me as standing at 27."

The other two are those of the "Exmouth" and "Inchulva." (16) With the "Exmouth" it will be remembered, the quicksilver disappeared in the tube of the barometer and did not appear again until nearly eight hours after the centre had passed. (17) In the case of the "Inchulva" the aneroid fell until its hand could go no lower, rising again as soon as the southwest wind struck the ship.

Recapitulating the barometric observations, we have the following list: —

| | | |
|---|---|---|
| 1. | False Point. | Slow rise through calm. |
| 2. | Manila. | Lowest before calm. |
| 3. | St. Pierre. | Steady in calm, with sharp minima at beginning and end. |
| 4. | "Star Republic." | Rise of three-tenths inch in calm. |
| 5. | "Idaho." | Rise at beginning of calm. |
| 6. | "Dione." | Steady during calm. Sudden rise at end. |
| 7. | Contai. | Steady during calm. |
| 8. | "Bridet." | Steady during calm. |
| 9. | "Britannia." | Aneroid agitated during calm. |
| 10. | Pondicherry. | Fall during calm. Rise two hours afterwards. |
| 11. | "Mersey." | Fall during nearly all of calm. Rise at end. |
| 12. | "Booldana." | Lowest at end of calm. |
| 13. | "Taicheong." | Fall during calm. Rise at end. |
| 14. | Midnapore. | Sharp minimum in middle of calm. |
| 15. | "Harkura." | Lowest some time in calm. |
| 16. | "Exmouth." | Mercury out of sight during calm and for eight hours after. |
| 17. | "Inchulva." | Aneroid as low as it would register during calm. Rise at end. |

Such various and apparently contradictory data make generalization at present impossible.

* Redfield: On the Avoidance of Cyclones, Amer. Jour. Sci. and Arts, XXIII., March, 1857, 207.

*Passage out of the centre.* — As the ship passes out of the centre the wind invariably, so far as can be learned, springs up with the same degree of suddenness with which it had previously moderated. Thus with the "Alexandra," it "became suddenly calm," and the calm ended with "a sudden blast from the northwest." At Manila there were alternate gusts and lulls from the west-northwest, absolute calm for two minutes, then alternate calm and gusts from the southwest before the hurricane recommenced. In the case of the "Taicheong" the wind moderated before the calm, and began again as gradually. This would seem to indicate that the same conditions prevailed all around the circle of winds.

*Dimensions of the calm.* — Following Dallas, I have made a list of such centre passages as gave the time during which the ship or station was involved in the calm. I have, also, in some cases where the ship did not cross the exact centre of the calm area, as shown by the shift of the wind, calculated the number of minutes required to cross the full diameter. With these data, when the rate of storm movement is given from other observations, the diameter of the calm is easily found. For land stations this calculation is sufficiently accurate, but in the case of vessels at sea, as no allowance is made for their movement while in the centre, it is only roughly approximate.

| Year. | Ship or Station. | Duration of calm in minutes. | Shift of Wind. | Estimated central passage in minutes. | Rate of Storm Movement. | Diameter in miles. | Authority. |
|---|---|---|---|---|---|---|---|
| 1687 | .................. | 120 | N.E.–S.W....... | 120 | ... | .... | Dampier. |
| 1780 | *Badger*........... | 30 | N.E.–S.W....... | 30 | ... | .... | Reid. |
| 1808 | *Tigris* .......... | 30 | ............... | ... | ... | .... | " |
| 1809 | *Northumberland*.... | 30 | S.E.–N.W. ..... | 30 | ... | .... | " |
| 1811 | .................. | ... | ............... | 120 | 9.2 | 18.5 | Piddington. |
| 1821 | Connecticut ....... | 15 | S.E.–N.W. ..... | 15 | ... | .... | Redfield. |
| 1821 | Cape May.......... | 15 | ............... | ... | ... | .... | " |
| 1837 | *Water Witch*...... | 10 | N.N.W.–S.W.. | 12 | ... | .... | Reid. |
| 1837 | *Athol*........... | 30 | N.E.–N.W...... | 42 | ... | .... | " |
| 1837 | *Judith and Esther*.. | 15 | ............... | ... | ... | .... | " |
| 1837 | *Rawlins*.......... | 60 | N.–S.W.. ..... | 65 | ... | ... | " |
| 1837 | Ship *West Indian*.. | 120 | ............... | ... | ... | .... | " |
| 1837 | Barque *West Indian*. | 60 | S.–W.......... | 85 | ... | .... | " |
| 1838 | *Carnatic*......... | 240 | S.W.–N.E. ..... | 240 | ... | .... | Thom. |
| 1840 | *Exmouth*.......... | 50 | ............... | ... | ... | .... | " |
| 1841 | *Windor* *.... ..... | 480 | S.W.–S.E....... | 677 | ... | .... | " |
| 1842 | *Whitby*........... | 90 | E.N.E.–S.W... | 92 | ... | .... | Piddington. |
| 1842 | *Ann Metcalf*...... | 30 | N.–S.......... | 30 | ... | .... | " |
| 1842 | Pondicherry........ | 40 | ............... | ... | ... | .... | " |
| 1842 | Calcutta........... | ... | ............... | 125 | 5.3 | 11 | " |
| .... | Mauritius.......... | ... | ............... | 432 | 5 | 21 | " |
| 1842 | *Samson* .......... | 15 | E. by S.–N.N.W. | 17 | 10 | 2.8 | Redfield. |
| 1843 | *Lady Feversham*.... | 15 | N.–S. ......... | 15 | ... | .... | Piddington. |
| 1844 | *Colombo*.......... | 20 | E.S.E. – N.N.W. | 20 | ... | .... | Redfield. |
| 1844 | *Reform*........... | 30 | S.E.–S.W...... | 42 | ... | .... | " |
| 1844 | *Star Republic*..... | 30 | E.S.E.–W....... | 31 | ... | .... | " |
| 1845 | *Arpenteur*......... | 40 | S.S.E.–N.W. ... | 41 | ... | .... | " |
| 1845 | *Hindustan*......... | 60 | E.–S........... | 85 | ... | .... | Dallas. |
| 1847 | *Buckinghamshire*... | 120 | E.S.E.–W.N.W. | 120 | ... | .... | Piddington. |
| 1854 | *Harkura*.......... | 30 | ............... | ... | ... | .... | Redfield. |
| 1858 | *Bridet* ........... | 75 | ............... | ... | ... | .... | Davy. |
| 1864 | *Alexandra*......... | 45 | ............... | ... | ... | .... | Gastrell and Blanford. |
| 1864 | Contai............. | 75 | – S.W.......... | ... | ... | .... | " " " |
| 1864 | Cowcolly .......... | ... | ............... | ... | ... | 28 | " " " |
| 1864 | Tumlook ........... | 30 | E.–W........... | 30 | ... | .... | " " " |
| 1864 | Koila Ghat. ........ | 60 | ............... | ... | ... | .... | " " " |
| 1864 | Santipore.......... | 45 | N.E.–W........ | 49 | ... | .... | " " " |
| 1866 | Nassau............ | 90 | ............... | ... | ... | .... | Buchan. |
| 1871 | *Mersey* (anchored).. | 35 | ............... | ... | 17 | 10 | Toynbee. |
| 1871 | St. Kitts........... | 22 | ............... | ... | 17 | .... | " |
| 1876 | Vizagapatam........ | 30 | ............... | ... | 3 | 1.5 | Eliot. |
| 1879 | [No name]......... | 60 | ............... | ... | ... | .... | Dallas. |
| 1881 | *Inchulva*.......... | 40 | N.E.–S.W....... | 40 | 7.2 | 4.8 | Chambers. |
| 1882 | Manila............. | ... | ............... | ... | ... | 15 | Kneeland. |
| 1884 | *Idaho*............ | 100 | S.E.–N......... | 108 | ... | .... | Gihon. |
| 1885 | *Britannia* ........ | 30 | E.–W.......... | 30 | 15 | 7.5 | Pedler. |
| 1885 | *Booldana* ......... | 45 | N.E.–S.W. ..... | 45 | 13 | 9.75 | " |
| 1885 | False Point........ | 20 | N.W.–W.S.W.. | 36 | 13 | 7.8 | " |
| 1886 | *Airlie*............ | 10 | N.N.W.–W.... | 18 | 3 | .9 | Eliot. |
| 1887 | *Albany* ...... ..... | 15 | ............... | ... | ... | .... | Dallas. |
| 1888 | *Chas. H. Marshall*.. | 20 | ............... | ... | ... | .... | Hayden. |
| 1888 | *Dione* ........... | 45 | ............... | ... | ... | .... | " |
| 1891 | *Taicheong*......... | 45 | ............... | ... | ... | .... | Seeman. |
| 1891 | *Wilhelm I*......... | 30 | E.–W.......... | 30 | ... | .... | U. S. Hydro. Office. |
| 1891 | *Weimar*........... | 30 | S.S.E.–W. ..... | 36 | ... | .... | " " " |

* This vortex is said to have been " moving slowly or in an irregular manner."

The most important point to note in connection with this table is the proportion of base to height in the calm centre. The average of all the diameters calculated from land observations is fourteen miles. Taking five miles as the height of the storm — an estimate too great, if anything, since storms which have calm centres are of low elevation,* we see that the eye of the storm is not a spool-shaped affair, but like a very flat box, with its base about three times its height.

(*To be continued.*)

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## SHALL WE ERECT LIGHTNING RODS? †

ALEXANDER MC ADIE, M. A.

IN this country as well as abroad, for some years past, there has been considerable doubt and uncertainty in the minds of thinking people, as to the expediency of erecting lightning rods upon their buildings. The true function of a rod, it is true, is not easily comprehended, yet it is more than passing strange, that with all the plain directions and explicit cautions from the many eminent minds that have studied the problem, there should still remain a wide-spread distrust of the methods in general use for protection against lightning.

"If I urge on Glasgow manufacturers," said Sir William Thomson, at the meeting of the British Association, at Aberdeen, "to put up lightning conductors, they say that it is cheaper to insure than to do so." Now, this was the opinion of practical men, business men, concerned only with questions of cost; but it will serve as fairly typical of the views held by others, and quite generally held, too; and underlying this opinion, one may readily perceive the belief that the risk was not great nor the protecttion so very certain. We are brought face to face then with the question, Does it pay to protect with our present methods?

Elsewhere can be found statistics, which although confessedly imperfect and fragmentary in character, leave no room to doubt that it certainly does pay to thus protect. The damage done by

* Eliot. Handbook of Cyc. Storms, 171. Cyclone Mem. III., 272. Pedler: Cyclone Mem. II.

† By permission of the Chief of the Weather Bureau.

lightning in the United States yearly is no inconsiderable quantity that may be passed over lightly. When we see that the number of deaths due directly to the action of lightning averages something like 200 per year (take the year 1891, 205 lives were thus lost, that we have an account of), and the damage to property at a minimum valuation, not below a million and a half dollars; and furthermore, that this is no isolated, exceptional catastrophe, but an established order of things, recurring with the regularity of the seasons, that part of our question which has reference to the amounts involved seems fully and definitely answered.

But do not let us assume for a moment that the liability to lightning stroke is the same for all places. The risk will vary greatly with locality. The Glasgow manufacturers answered the eminent man of science more wisely, perhaps, than they themselves knew. Thanks to the investigations of the Prussian Bureau of Statistics, we know, now, that these manufacturers were *in the main* right, for the reason that in thickly settled communities the risk is small compared with other localities. There are good reasons why, speaking generally, we can state that there is but little need for the erection of lightning rods upon buildings standing among others in city blocks. It is not true that such buildings are never struck. In the chapter on Accidents,* it is clearly shown that under certain conditions the question of "exposure" seemingly has very little to do with the determination of the path of discharge of intense flashes. The case is somewhat analogous to that of the trees and rocks upon a mountain side, which however much they may determine the course of small mountain streams, are powerless to influence the course of an avalanche or land-slide. Sometimes, therefore, such buildings are struck and severely injured, and in exceptional cases, even where seemingly well protected; but for all that, it may still safely be set down that the erection of rods upon small city houses is not altogether a matter of necessity, as has been maintained by some.

Secondly. In cases of flashes of ordinary intensity, how certain is the protection afforded by a good rod? Few questions have been so thoroughly discussed from a practical as well as theoretical standpoint. No matter what Lodge's experiments

* In a report upon "Protection from Lightning."

may seem to indicate as to the uncertainty of our present methods, cold hard facts cannot be disregarded. We find, that those who have gone deepest into the investigation of accidents resulting from lightning have seen clearly in the end, although sometimes after much doubting and perplexity, that the suggestion and plan of the American philosopher of 1755, for the protection of life and property from the dangers of lightning, are correct theoretically and in practice successful. What a list of names can be brought forward in support of this statement: Cavendish, Coulomb, LaPlace, Davy, Faraday, Harris, Henry, Von Helmholtz and Clerk Maxwell; Arago, Abbadie, Ayrton, Beccaria, the Becquerels, Babinet, Buchner, Charles, Canton, Callaud, Colladon, Clark, De la Rive, De la Rue, De la Tour, DeSaussure, Dulong, Despretz, Duprez, Duhamel, DuMoncel, Fresnel, Fizeau, Gay-Lussac, Girard, Henly, Holtz, Kirchhoff, Karsten, Mann, Melsens, Mohn, Nairne, Priestly, Pringle, Peltier, Poey Poisson, Pouillet, Preece, Reimarus, Rochon, Regnault, Werner, von Siemens, Tait, Tomlinson, Toepler, the Varleys, Watson, Wilson, Weber, Walker, Zenger, and a host of others. And as a result of their labors we know that, provided certain precautions are taken, rods do effectually protect against the flash itself, as well as ward off the occurrence of discharge.

Snow Harris, perhaps, went more thoroughly into the question of the relation of the form of the conductor to protection than any one else. He experimented considerably, but as a matter of fact, derived his best information from extensive study of the effects of actual flashes themselves rather than from laboratory work. And in this, in the long run, he proved himself wiser than Faraday. For Faraday, in 1850, seeing only the question of conductivity in the problem, said decidedly that this was a simple question of conductivity and that "*surface did nothing,— the solid section was the essential consideration.*" The weight of his deservedly great fame settled the questions upon this basis* for many years, although Harris, with the records of years before him, knew that whatever theory might seem to demand, the facts were plain that surface area was of very great if not equal importance with solid section in dealing with lightning discharges. So in the experiments of Dr. Lodge, to be referred to further on, there is

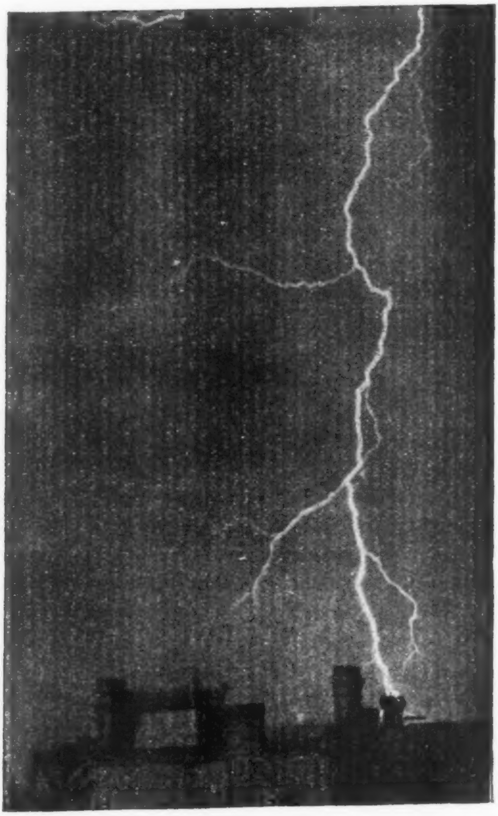
* Almost all recent writers have followed this view.

some uncertainty whether or not he has really duplicated the natural cases.

But the public meanwhile was drifting somewhat into the position of that old British Admiral, who being called upon to approve some specifications for a lightning conductor upon a certain light-house, although himself a believer in the surface theory of Harris, yet thought he would go down and consult Faraday about the matter. Now Faraday said very positively that the solid rod was better than the tube (which would give greater surface with less copper), that solid volume was everything, superficial area nothing, and that if Harris says otherwise, then "he knows nothing whatever about it!" The Admiral straightway approved the solid rod conductor for the light-house. Within a day or so he met Harris, and instancing the matter, the latter said, "Surface area is most important, and if Faraday says otherwise, then he knows nothing whatever about it!" Small wonder then that the public should be likewise somewhat embarrassed by such conflicting directions from two such authorities. We now know that Harris was right (yet, paradoxical as it may seem, Faraday's position *as far as it goes* is correct and unassailable; and his recommendations for all practical purposes, as important to-day as when made), but for nearly forty years following 1850, and despite facts which proved the success of his methods in the protection of ships and public buildings, Harris's views on the importance of surface area were overlooked.

In 1882 came the report of the Lightning Rod Conference; and this is in many respects the most important contribution to the literature of the subject ever made. While so many foreign governments (and France in particular) had, by means of officially constituted boards, taken a governmental interest in the protection of the people from the dangers of lightning, the English speaking people of the world, aside from the few directions for the protection of magazines, light-houses, etc., were without any authoritative utterance to which they might refer. The conference, while not strictly an official body, from the character of its members, carries even greater weight. It was simply a joint committee of representative members of the Institute of British Architects, the Physical Society, the Society of Telegraph Engineers and Electricians, the Meteorological Society and two co-opted members. As was to have been expected from such

auspices, the report is an excellent one, and must stand for years as the embodiment of the most widely gathered information and well considered decisions.



LIGHTNING AT WASHINGTON, D. C., AUG. 29, 1891, AT 8.15 P. M. PHOTOGRAPHED BY A. MC ADIE.

In 1888 Dr. Oliver J. Lodge began his remarkable course of lectures upon the oscillatory character of the lightning flash. The views advanced by him are of such importance that the substance of each lecture is reproduced at length in chapters V. and VII.* It is enough here to simply emphasize the fact that

* Report above cited.

if any electric current flows steadily in one direction in a cylindrical wire, its intensity is the same in all parts of the wire; but if, as shown by Hertz, the current be of an oscillatory character, *i. e.*, a current which reverses rapidly its direction, this condition no longer holds; and if the direction is altered with sufficient rapidity, the interior of the wire (in our case the lightning rod), may be almost free from current. "This," says Lodge very eloquently, "is one of the direct results of the investigation of the propagation of electric waves in all media, the fruit which we now enjoy of the rich plantings of Maxwell (for whom, by the way, Faraday cleared the ground)." And this principle seems to Lodge to be of the utmost importance in investigating the action of lightning. "If lightning is a discharge of an oscillatory character, and some of us think that it is, then the theory of the lightning rod, as regards all that section below the point, requires alteration."

Of course, in places, this view of the character of the flash is at variance with the decisions of the Conference and in consequence thereof, a discussion (now famous) occurred at the British Association meeting in 1888. The honors seemed to be about evenly divided, for while Lodge had undoubtedly the clearer insight into the character of the lightning flash, the decisions of the Conference were not successfully assailed. The attitudes of the Conference and Lodge seem to me to be somewhat like the positions of Faraday and Harris.

If the reader is contemplating the erection of a rod, these points may be of service to him.

1. Get a good iron or copper conductor; if the latter, that which will weigh about six ounces to the foot, and preferably in the form of tape; if iron is used, and it is, perhaps, if anything the better, have it in rod or tape form and weighing about thirty-five ounces to the foot.

2. The nature of the locality will determine to a great degree the need of a rod. Places apart but a few miles will differ greatly in the relative frequency of flashes. In some localities the erection of a rod is imperative, in others, needless.

3. The very best ground you can get is after all for some flashes but a very poor one, therefore do not imagine that you can overdo it in making a good ground. For a great many flashes any ordinary ground will suffice, but the small resistance

of even one ohm for an intense oscillatory flash may be dangerous.

4. "If the conductor at any part of its course goes near water or gas mains it is best to connect it to them. Wherever one metal ramification approaches another it is best to connect them metallically. The neighborhood of small bore fusible gas pipes and indoor gas pipes in general, should be avoided." *Lodge.*

5. The top of the rod should be plated, or in some way protected from corrosion and rust.

6. Independent grounds are preferable to water and gas mains.

7. Clusters of points or groups of two or three along the ridge rod are recommended.

8. Chain or link conductors are of little use.

9. Area of protection. Very little faith is to be placed in the so-called area of protection.

10. Indifference of lightning to the path of least resistance. Nearly every one who has written of late years upon this question, has taken it for granted that lightning always follows the path of least resistance. This is not true. "It is simply hopeless to pretend to be able to make the lightning conductor so much the easier path, that all others are out of the question," says Lodge. However, this requires some modification. The path will depend largely upon the character of the flash. For some flashes the statement as it stands above is true (and it can even be shown that at times points seem to lose their protective powers), but without doubt for almost all flashes a good lightning rod well earthed is the appropriate path to earth, and the rod may be relied upon to so act at the proper time.

11. Any part of a building, if the flash be of a certain character, may be struck, whether there is a rod on the building or not. Fortunately this is the rarely exceptional case, the great majority of flashes in these latitudes being comparatively mild, and not at all as dangerous as we are apt to imagine them to be. We have instanced several cases where edifices seemingly amply protected have been struck below the rods (not to be confounded with cases of defective rods, etc.); and it is now becoming plain to us how (paradox of paradoxes) a building may be seriously damaged by lightning, *without having been struck at all.* Take the famous Hotel de Ville of Brussels, so well protected by Mel-

sens' method, we might add, perhaps, the best protected building in the world, against lightning, and yet it was damaged by fire caused by a small induced spark near escaping gas. During the thunderstorm some one flash started up "surgings" in a piece of metal not connected in any way with the protective train of metal. The building probably "did not receive" says Dr. Lodge, "even a side flash, yet the induced surgings set up in it, induced by Maxwell and Heaviside's electromagnetic waves, were so violent as to ignite some gas and cause a small fire." In other words, we had the condition of an "oscillator" in the cloud-flash-earth system, and the "resonator" in the piece of metal, that responded with its little spark. In some experiments made by the writer during intense flashings, simultaneously with the flashes were seen small sparks between metallic ends, which we assume were of this character. We have to guard then against this heretofore unknown source of danger from within.

12. Unnecessary alarm. Many people suffer from alarm in addition to the sufferings due to nervousness during the prevalence of thunderstorms. Now the fact is, that there are many flashes of lightning that the human body can withstand without very serious effects. Voltaire's caustic witticism "that there are some great lords which it does not do to approach too closely; and lightning is one of these," apropos of the death of Richman, at St. Petersburg, while experimenting, needs revision in these days when we deal daily with currents that are of greater electrical energy. Indeed, the other "*bon mot*," "*Le ciel a plus de tonnerres pour épouvanter qu'il n'a de foudres pour punir*" (Heaven has more thunders to alarm than thunder-bolts to punish), has just so much more point to it as it is nearer to the truth. One who lives to see the flash need not concern himself, or herself, much about the possibility of personal injury from that flash.

13. The notion that lightning never strikes twice on the same place is wide-spread, but erroneous; and we have plenty of cases showing the contrary to be true. The interval may be a day, a few minutes, or years.

14. Finally, if you should be in the vicinity of a person who has just been struck by lightning, go to work at once to try to restore consciousness. We have cases on record where after severe lightning stroke it has yet been possible to bring back to

life the seemingly dead. We have reason to believe that many such accidents result in "suspended animation" rather than instant death. Try to stimulate the respiration and circulation; and do not cease in the effort to restore animation for at least one hour.

For an excellent illustration of a case of severe lightning shock and recovery, due it would seem almost entirely to proper and prompt management by the medical men present, see the *Medical News*, August 11, 1888.

U. S. WEATHER BUREAU, WASHINGTON, D. C., May, 1892.

# CURRENT NOTES.

## NEW ENGLAND METEOROLOGICAL SOCIETY.

In the May number of this JOURNAL mention was made of the vote of the New England Meteorological Society to transfer the work of routine observation to the United States Weather Bureau, for the formation of the New England Weather Service. Profs. Davis and Upton, who were appointed a committee to prepare a circular explaining this action, have recently issued this circular, which has been sent to the members, observers and correspondents of the Society. From it the following extracts are taken.

The New England Weather Service will be under the direction of the National Weather Bureau, and will be locally in charge of Mr. J. Warren Smith, who for nearly two years past has been detailed first by the United States Signal Service, and later by the Weather Bureau of the Department of Agriculture, to act as assistant to our Society in its weather-service work. Mr. Smith's office will hereafter be in the Post-Office Building, Boston, where all reports to him should be addressed. The new service will continue to issue a monthly bulletin somewhat enlarged from the present form. It will be, as heretofore, sent to all reporting observers, who are earnestly requested to continue with the New England Weather Service the assistance that they have so perseveringly rendered the Society. The bulletins will also be sent for the current year to all members and correspondents of the Society as heretofore.

The library collected by the Society will be divided, one part being transferred to the New England Weather Service, the other part to the Meteorological Library of the Harvard College Observatory, at Cambridge, Mass. As the investigations of the Society will be published in the Annals of the Observatory, it is requested that exchanges be sent only to the Library of the Observatory, and not also to the Society, as heretofore.

The immediate effect of this change upon the Society will be the relief of its chief burden, which has more than exhausted its treasury and which could not have been carried on at all but for assistance from the National Weather Service and the Observatory of Harvard College. In fact, the work has practically been done by these co-operating institutions for several years, the Society exercising a supervision increasingly nominal and contributing a part of the expense of its maintenance. The work of carrying on special investigations, like those of thunderstorms, the sea-breeze, and the study of special storms, with the holding of meetings, will become the chief work of the Society, as was intended at its organization.

At the annual meeting in October, the Council will present to the Society detailed suggestions for its future under the new conditions, which cannot now be fully explained. The cordial co-operation of the members and friends of the Society is bespoken for the work of the New England Weather Service as well as for the continued maintenance of the Society itself.

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## ROYAL METEOROLOGICAL SOCIETY.

The usual monthly meeting of this Society was held on Wednesday evening, April 20, at the Institution of Civil Engineers, 25 Great George Street, Westminster; Dr. C. Theodore Williams, President, in the chair.

The following papers were read : —

"Anemometer Comparisons," by Mr. W. H. Dines, B. A., F. R. Met. Soc. This was a report on a valuable series of experiments, which have been carried out at the request of the Council of the Society, with the view of obtaining a direct comparison of the various anemometers in common use, so that some opinion might be formed as to which type of instrument is the most suitable for general purposes. The Meteorogical Council have defrayed the cost of the work. The anemometers which were compared were: 1. Kew-Pattern Robinson. 2. Self-adjusting Helicoid. 3. Air Meter. 4. Circular Pressure Plate (one foot in diameter), and 5. A special modification of Tube Anemometer. Most of these instruments are of the author's own invention, as well as the apparatus for obtaining automatic and simultaneous records from all the instruments upon the same sheet of paper. It appears that the factor of the Kew-Pattern Robinson is practically constant and must lie between 2.00 and 2.20. The Helicoid Anemometer is quite independent of friction for all excepting light winds, and different sizes read alike, but it is not so simple in construction as the cup form. The Air Meter consists of a single screw blade formed of thin aluminium and made as nearly as possible into the exact shape of a portion of a Helicoid. A similar instrument with a larger blade, and with the dial protected from the weather, would probably form a useful and correct Anemometer. It would be light and offer a very trifling resistance to the wind. The oscillations of the pressure plate must have been considerably damped by the action of the floating weight, but as it was, they were sufficiently violent. It seems probable that the remarkably high values sometimes given by the Osler Pressure Plate may be due to the inertia of the moving parts. The Tube Anemometer appears to possess numerous advantages. The head is simple in construction and so strong that it is practically indestructible by the most violent hurricane. The recording apparatus can be placed at any reasonable distance from the head, and the connecting pipes may go round several sharp corners without harm. The power is conveyed from the head without loss by friction, and hence the instrument may be made sensitive to very low velocities without impairing its ability to resist the most severe gale.

"The Hurricane over the West Indies, Aug. 18-27, 1891," by Mr. F.

Watts. The author has collected a number of observations on this violent hurricane, which, on Aug. 18, swept from the Atlantic into the Caribbean Sea, and moved in a northwesterly direction over San Domingo, and thence northward and eastward.

At Martinique the barometer, which at 5.30 P. M. stood at 29.80 in., fell to 28.38 in., at 8.15 P. M., during the passing of the centre of the cyclone.

*Exposure of Rain-Gauges.* — In the Annual Report for 1892 of the Berlin branch of the German Meteorological Society, Prof. G. Hellman gives an account of his continued experiments on the effects of exposure on rainfall records, and on the determination of the distance apart that rain-gauges should be erected in order to obtain an accurate account of the rainfall of any district. Simple as the question appears, the experiments, which have been carried on for seven years, have not sufficed to give a definite answer. Very considerable differences are found in the amounts recorded at stations comparatively close to each other. This result is partly owing to the effect of the wind, especially in the case of snow. The following are the most important conclusions derived from the experiments: (1) The more a rain-gauge is exposed to the wind, under otherwise similar circumstances, the less rainfall it records, and the higher a gauge is placed above the ground, the less rain it catches, as the disturbing influence of the wind is greater than on the surface of the ground. But if properly protected from the wind, a gauge will give useful results in an elevated position. The usual instructions to erect a gauge as openly as possible are therefore incorrect. (2) Even in a flat country, differences of five per cent occur in different months, at stations a quarter of a mile apart; in stormy weather, especially during thunderstorms, the differences may amount to one hundred per cent. The amounts recorded at neighboring stations agree better together in spring and autumn, and also in relatively wet years. Further experiments are needed, if possible by means of anemometers erected at the same level as the rain-gauges, to determine more accurately the effect of the wind on both rainfall and snow. — *Nature.*

*English Weather Forecasts.* — According to "Nature" the percentage of success in the weather forecasts issued by the Meteorological Council at 8.30 P. M. daily during the year ending March 31, 1892, was eighty-two. The results were best in the south of England, where the verifications were eighty-eight per cent, and worst in the south of Ireland, where the percentage of success was seventy-seven.

*Avalanches and Wind-Flurries.*—In this JOURNAL, Vol. IV., p. 512, Prof. W. M. Davis gave a classification of the winds, under which one class is spoken of as land-slide winds. Of these the writer says: —

"Land-slide winds are as destructive as they are exceptional; they are winds that are brushed forward by a land-slide, so as to advance much beyond the limits of the slide with sufficient violence to overturn trees and houses. Such winds are well known in Switzerland."

In this connection it is interesting to note the occurrence of such accidental winds in front of avalanches in Canada, mentioned in an address before

the American Society of Civil Engineers, June 28, 1888, by Thomas C. Keefer, the President of the Society. "Remarkable effects," the speaker said, "are produced by the local cyclone or hurricane induced by the swift avalanches. This sometimes extends for one hundred yards outside the course of the solid avalanche and is called the "flurry" because it is clouded with particles of fine snow. If the course of the avalanche is diverted by some natural obstacle, the flurry drives on in the line of original motion, snapping off huge trees several feet in diameter, at heights fifty feet or more above the ground, without uprooting them. Some in the vortex of the flurry are uprooted, but the majority are cut short off, as they would be by chain-shot, and so far from the line of the avalanche that there is nothing to indicate the cause of their decapitation but the snow, impacted like moss against the windward side of their huge trunks. The flurry whirls upward to a height of one hundred feet above the descending snow, and forward in advance of it when under full headway, presenting a magnificent spectacle to an observer when at a safe distance."

In a pamphlet on the Avalanches of the Swiss Alps (Die Lauinen der Schweizeralpen), Coaz speaks of these winds in Switzerland as follows: "The air is very much compressed by this falling cloud of snow, and flows as a hurricane in front of the avalanche down into the valley, followed closely by the latter, and continually driven on to more rapid flight. If the blast of air is contracted by a narrowing of the valley, its pressure is thereby increased, and its rush through the valley becomes more violent and destructive. Whole forests succumb to its fury." Various instances of such winds are noted. The blast from an avalanche in the Gadmenthal (Bern) broke off a number of trees in a wood five hundred meters away. A remarkable case occurred in connection with an avalanche which came down the west side of the Jungfrau on May 1, 1879. The wind caused by it was so violent that it rushed across the valley below and prostrated the trees in a forest on the other side of it, three hundred or four hundred meters away, and the light snow was carried as a "flurry" two thousand five hundred meters in a straight line away from the scene of the avalanche.

# BIBLIOGRAPHICAL NOTES.

## INVESTIGATIONS OF THE NEW ENGLAND METEOROLOGICAL SOCIETY.

The Investigations of this Society for 1890 are published in Part 1 of Vol. XXXI. of the Annals of the Astronomical Observatory of Harvard College. (Pages 1–156, 5 plates.) The publication consists of a meteorological summary of the year 1890, with eight tables containing various data; of a set of five-year tables of temperature and precipitation for New England, by J. Warren Smith, late assistant to the Director of the New England Meteorological Society and now Director of the New England Weather Service, and of three articles on the tornado at Lawrence, Mass., July 26, 1890. The pentad tables give the five-year normals of temperature and precipitation at the various stations of the Society. No attempt has been made to discuss the data, which are only such as are known to be reliable. No means have been used for less than five years, and no period has been entered that did not contain at least six complete monthly pentads. Accurate record is made of the latitude and longitude of each station, the elevation, the source from which the records were obtained, and of the hours at which observations were made. The tables represent a great amount of labor, and are a very valuable contribution to the data already at hand with reference to the climatology of New England. It is to be hoped that a discussion of these tables will soon follow, now that the material has been brought to a condition in which it can easily be used.

The articles on the Lawrence tornado are three in number. The first on "The Features of Tornadoes and their Distinction from other Storms," by Prof. W. M. Davis, the Director of the Society; the second on "The Lawrence Tornado," by H. Helm Clayton, of Blue Hill Observatory, and the third on "The Evidences of Vorticular Motion in the Lawrence Tornado," by Hiram F. Mills, C. E. Accompanying the articles are reproductions of four photographs illustrating the damage done by the tornado. Brief abstracts of these papers have already been given in this JOURNAL (Vol. VII., pages 433–439).

## CORRESPONDENCE.

### A REMARKABLE RAINBOW.

*Editor American Meteorological Journal:—*

A notice of a rather remarkable rainbow which I observed a little after six last evening may be of interest. The primary or inner bow was fully formed, and the secondary, or outer, extended from the ground to a length of about 45°. Inside the primary, and closely connected with it and with each other, were three of the so-called "spurious," or supernumerary bows, and faint traces of a fourth were visible. Thus, not including the partly-formed secondary, or outer bow, which was not multiple, there were *four* distinct, concentric, equidistant circles of red, the spaces between being occupied by the fainter spectrum colors. Low masses of scud passed beneath the apparent position of the bow, slightly obscuring it at times.

A. L. COLTON.

WASHINGTON, D. C., May 3, 1892.

### EDITORIAL NOTE.

We desire again to call attention to the change in management and in the place of publication of the JOURNAL, beginning with the May number, the first of the ninth volume. As was stated in the April number, Prof. Harrington and Mr. Rotch have given up their positions as editors, but they will both continue their interest in the JOURNAL as contributing editors. Prof. Cleveland Abbe, of the Weather Bureau at Washington, and Prof. W. M. Davis, of Harvard University, both of whom are well-known writers on meteorological matters, have also joined the board of contributing editors. Messrs. Ginn & Co., of Boston, are to have charge of the publication of the JOURNAL.

It is the intention of the editor to make the JOURNAL a review, so far as possible, of the principal writings in connection with meteorology both in this country and in Europe. Each number will contain some original articles on various subjects, current notes on matters of general interest, bibliographical notes on recent articles and books, and correspondence. In order to carry out his plan of making the JOURNAL as representative as possible of the work of American meteorology, the editor would be very glad to have contributions on matters of general interest from any source. Correspondence is invited on subjects connected with meteorology in any of its branches. Notes are desired from persons who may have any special phenomena to report, in connection with the general course of the weather, as well as concerning exceptional occurrences. Contributors of original articles will be supplied free with five copies of the issue containing their articles, and additional copies can be had at low rates.

All contributions, exchanges, and matters relating to the contents of the JOURNAL should be sent to the editor, whose address is Cambridge, Mass. Communications relating to business matters should be sent to the publishers, Ginn & Co., Tremont Place, Boston, Mass.